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Intersections of Behavior Analysis with Cognitive Models of Contingency Detection

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Bower and Watson have offered, respectively, a logical hypothesis-testing model and a conditional probability model of contingency detection by young infants. Although each could represent cognitive processes concomitant with operant learning, empirical support for these models is sparse. The limitations of each model are discussed, and suggestions are made for a more parsimonious approach by focusing on the areas of overlap between the two.

Key words: contingency detection, learning, logical hypothesis testing, infants

Learning behavior-contingent relations is crucial to normal infant development. Perhaps the most important contingent relations are those that occur between the infant's behavior and functional social stimuli. Research has shown that infant operant behavior is readily conditioned by social reinforcers (Etzel & Gewirtz, 1967; Pelaez-Nogueras et al., 1996).

Such studies typically involve contrasting a continuous reinforcement (CRF) condition with a control condition of differential reinforcement of other (DRO), incompatible (DRI), or alternative (DRA) behavior. The CRF condition represents a perfect contingency, where A is necessary and sufficient to cause B, whereas in the control condition B is never contingent on A. However, such perfection usually occurs only in the laboratory. The typical social situation is one of intermittent reinforcement and intermittent noncontingent access to the reinforcer. For example, when an infant cries, sometimes the mother comes and sometimes she does not come; when it does not cry, sometimes the mother comes and sometimes she does not come. In addition, sometimes she comes right away and sometimes her appearance is delayed. The typical social situation is clearly not like the operant conditioning situation that is typically studied in the laboratory with infants. Yet infant behavior comes under control of its social environment quite well. Operant behaviors are routinely emitted in ways that ensure the infant's viability.

Bower and Watson have offered alternative explanations of contingency detection by infants. Bower asserts that a logical analysis model is most appropriate, whereas Watson argues for a conditional probability analysis model. It should be noted that these models are not models of behavior per se. In behavior analysis, the unit of interest is the response, and systematic variations in responding are interpreted as learning that is an outcome of conditioning operations. The contingency detection models espoused by Bower and Watson are interested in a presumed internal analytic process. Systematic variations in responding are taken as indices of this process, rather than simply attributed to the conditioning operation. Indeed, studies with adults that have tested similar models include the subjects' judgments of contingency as dependent variables in addition to or instead of operant measures (Bauer, 1972; Shanks, 1993). Because Bower's and Watson's subjects are preverbal, their judgments must be inferred from their pattern of overt responding.

The different orientations between behavior analysis and that represented by Bower and Watson lead to conceptually different levels of analysis of

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how the organism adapts to a dynamic flux of environmental conditions. The two models under consideration here represent cognitive processes that are presumably concomitant with operant learning. In other words, these models are an attempt to peek inside the proverbial black box.

From a behavior-analytic perspective, the mysteries of the box are not compelling. It is simply assumed, for example, that if a contingency is learned, it has been detected. Thus, although behavior analysis accepts that cognitive as well as other organismic processes occur, these processes are not considered germane to the science of behavior. One reason for this is the level of inference necessary when dealing with phenomena, cognitive or otherwise, that are once removed from overt responding. Nevertheless, many researchers who operate outside of behavior-analytic theory have capitalized on operant paradigms to test nonbehavioral models. This is the case with the works presented here by Bower and Watson.

Behavior analysts would do well *not* to ignore such research. Intersection of behavior analysis with other perspectives, such as those discussed here, may have benefits for both sets of research. It is in this spirit that the remainder of this paper is written. The following sections provide commentary and what I hope is constructive criticism of the models of contingency detection proposed by Bower and Watson.

Concerns with the Logical Hypothesis-Testing Model

In his cogently presented thesis, Bower makes several points for logical hypothesis testing that require further consideration. First, the reported increase in variance of intersuck intervals associated with the introduction of suck-contingent stimulation (CRF) can be viewed as another example of operant conditioning without appealing to hypothesis testing. Increases in long as well as short pauses, relative to baseline, would necessarily increase the associated variance, and a greater increase in short, relative to long, pauses would result in a lower pause mean. In essence, what the infants seem to do upon the introduction of CRF is to increase rapid sucking bursts and then take a break between bursts.

What is the nature of the increase in long pauses following bursts of responding? Bower asserts that it is a product of hypothesis testing. It could be reasonably expected, however, that high-frequency responding would be followed by a period of rest. Longer pauses may be due to physiological factors such as fatigue or an energy-conservation mechanism. Evidence for such a mechanism is suggested by studies that show longer postreinforcement pauses and lower response rates as reinforcement ratios increase (i.e., ratio strain; Mazur, 1983). This competing hypothesis has yet to be ruled out.

Second, the logical hypothesis-testing model predicts infant behavior under limited conditions. The model's predictions are premised on shifting either from baseline (no reinforcement) to CRF or from CRF to intermittent reinforcement or noncontingent stimulation. The model should also predict responding under a variety of other schedules and schedule shifts.

Haith (1966) reported similar findings that appear to be consistent with the logical model, but the results of other studies are less clearly predicted by the model (DeCasper & Carstens, 1981; DeCasper & Sigafoos, 1983; DeCasper & Spence, 1986). DeCasper and Carstens, for example, found that infants who first receive noncontingent stimulation showed no significant change in intersuck intervals when shifted to a CRF schedule. Although this result appears to be a learned helplessness effect (Seligman, 1975), it does not appear to be consistent with a logical hypothesis-testing approach.

Third, if differential patterns of responding associated with different schedules of reinforcement are indeed a result of hypothesis testing, then very similar patterns of responding should be obtained across a variety of responses over a broad developmental period. Such evidence does not exist in the current developmental literature. One reason may be that most researchers do not report interresponse intervals, making it impossible to determine if the obtained results would be predicted by Bower's logical analysis.

Concerns with the Conditional Probability Model

Turning now to conditional probability, the model presented by Watson analyzes the probabilistic temporal structure of response–stimulus relations. The statistical validity of the model seems unquestionable. Yet, it is this very fact that is perhaps the model's greatest weakness with respect to its ecological validity.

The conditional probability analysis requires not only computation of probabilities based on known variables, such as the sum of responses (R), but also of variables that are usually known only to the experimenter, such as the unconditional probability of the stimulus (S) (Watson, 1979). Without such known probabilities, the model is unreliable. In natural settings, for example, the infant will likely not know the unconditional probability of S nor will it know the sum of S. Thus, the ecological validity of such a conditional probability model is questionable, except in very limited cases in which the infant has access to all of the necessary variables.

Watson also asserts that one of the benefits of conditional probability analysis is that it allows for the calculation of statistical confidence. At the same time he points out that other, simpler systems of contingency detection may be used early in life or in certain contexts. It is unclear why statistical quantification is a benefit when simpler systems may be sufficient. Although it is true that infant behavior is sensitive to quantitative values of stimulus events, that does not mean that infants statistically analyze those values. Again, reliable patterns of responding would logically be statistically predictable as well.

Another weakness of the conditional probability model is that it does not identify, or suggest, a mechanism of analysis. Watson alludes to an innate detection system and implies that he does not believe that infants consciously perform probability analyses. However, it is unclear what the mechanism might be. This issue merits further exploration, because a plausible mechanism would add credence to the model.

Moreover, assuming that a biological function exists that can approximate the statistical operations associated with a conditional probability analysis, the model presented by Watson, like that presented by Bower, may still be unnecessarily complex. This issue will be further explored in the following section.

Simplifying the Models

Both the conditional probability and hypothesis-testing models provide a plausible basis for processes involved in learning. It is unlikely, however, that both are veridical models of contingency detection by infants. Watson's conditional probability analysis requires that the probability of a given event (S) following a given response (R) be contrasted with the probability that S will occur randomly from any given time (t). Thus, the infant must perform statistical computations. Bower's logical model requires that the infant be sensitive to the temporal sequencing of the occurrence of R and S or their nonoccurrence ($\bar{R}$, $\bar{S}$) in order to test hypotheses of R-S relations. The question then is not so much which model more accurately predicts behavior but which of the two models is more representative of how the infant actually behaves with respect to contingencies. It seems logical that nature would select the simplest, least taxing mechanisms of learning that can get the job done without compromising the organism's survival. Both the logical and conditional probability models of contingency detection seem to involve a degree of overkill in this regard.

The logical analysis model could be made more parsimonious by dropping the $\bar{R} \rightarrow \bar{S}$ relation. There are at least four reasonable considerations for doing so. First, $\bar{R} \rightarrow \bar{S}$ will certainly constitute the bulk of all response–stimulus experiences. Thus, it would not seem to be adaptive for the infant to test instances of nonoccurrences of both the behavior and the stimulus. Otherwise, he or she would be in a state of perpetual hypothesis testing. Second, the $\bar{R} \rightarrow \bar{S}$ relation is largely uninformative. It says nothing about the positive contingency that may exist between R and S, whereas the other three relations do. Thus, and third, $\bar{R} \rightarrow \bar{S}$ is only informative when contrasted with one of the other three relations. Fourth, information acquired by testing $\bar{R} \rightarrow \bar{S}$ can also be derived from tests of $\bar{R} \rightarrow S$ and $R \rightarrow \bar{S}$, because these two relations would presumably capture all occurrences of R and S.

To push this reductionism a bit further, it is possible for fairly accurate contingency detection to occur by testing only $R \rightarrow S$ and $R \rightarrow \bar{S}$. Even in cases in which $\bar{R} \rightarrow S$ occurs at a very high rate, what may be important for the organism is to learn that R is a sufficient condition for S. In addition, a high rate of $\bar{R} \rightarrow S$ does not mean that a contingency does not exist. Although learning will likely be slowed under such conditions, it will not necessarily be prevented (Watson, 1979). Other contextual and behavioral factors may operate to facilitate learning in such situations.

With respect to conditional probability analysis, it may suffice for the infant to assess the likelihood that S will follow R relative to the likelihood that R will precede S in order to make an accurate assessment of a contingency and its relative strength. Contingency detection may occur on the basis of a cumulative mathematical process rather than probabilistic statistical analysis. Furthermore, the unconditional probabilities of R and S may be unknown (as previously stated) or unnecessary for accurate detection of contingencies to occur.

Unifying the Simplified Models

It may be reasonably asserted that in analyzing the relation between R and S, an infant would reach the same conclusion whether the infant conducted the equivalent of a conditional probability analysis or a test of logical hypotheses. It seems that both models would yield the same outcome in most, if not all, cases. Despite conceptual differences, pragmatically the models appear to be quite compatible. In fact they seem more similar than different, particularly when comparing the simplified versions suggested above. Perhaps focusing on points of compatibility between the two models can be useful in narrowing down the process of contingency detection.

The likelihood that S will follow R can be determined by contrasting the relations $R \rightarrow S$ and $R \rightarrow \bar{S}$, not numerically or statistically perhaps, but functionally. Likewise, the probability that S will occur randomly is functionally equivalent to testing the $\bar{R} \rightarrow S$ relation. Thus, the two models may be collapsed into the analysis of three relations, $R \rightarrow S$, $R \rightarrow \bar{S}$, and $\bar{R} \rightarrow S$, with the latter being less informative than the first two. The analysis could be of a mathematical nature, with the relative frequencies of each event having a cumulative effect on contingency detection.

A major weakness of the minimalist suggestion just made is that it will almost surely lead to more errors on the part of the infant, and therefore more protracted learning. A final point may ameliorate this difficulty. Specifically, it is apparent, given the changing nature of the environment, that learning is flexible. Learning is not a terminal response that occurs at the moment a contingency is learned. It is a process in which R-S relations are continually validated or revised with experience. Over time the infant will have the opportunity to make more accurate assessments of contingencies. Thus, the role of additional experience, and other contextual determinants, should not be underestimated.

Conclusion

Developmentalists, including behavior analysts, should remain open, albeit guardedly so, to the possibility that processes like those proposed by Bower and Watson are relevant to operant learning. At present there are several limitations to the empirical evidence favoring the proposed models.

First, there is not enough of it. Far more research is needed to establish the predictive parameters and validity of each model. Research should also lead to the development of a single, parsimonious model of contingency detection that capitalizes on the most useful postulates suggested by each of the models at issue here, as well as others. Second, at least some of the existing evidence is not consistent with the models. Empirical evidence that does not clearly fit the models should be addressed. Such evidence may be the result of differences in testing procedures or could represent a weakness of the models. Third, it is important to establish, in the case of the logical model, that the predictive value of the model is not exclusive to neonatal sucking behavior. Fourth, the models themselves seem excessively complex to be ecologically practical. Perhaps the authors might test some of the suggestions for simplification made here. A more parsimonious model of contingency detection is intuitively appealing, although not necessarily more accurate with respect to infants' capabilities.

The fifth, and perhaps most serious, limitation of the models proposed by Bower and Watson is that they are testable only in a limited sense. The fact that operant conditioning produces highly reliable changes in behavior makes it possible to develop models that reliably predict those behavior patterns. Thus, the models may only appear to explain behavior. For example, one could develop a model that would predict that the sun rises and sets in 24-hr intervals. This description leads to accurate predictions, but it does not explain the phenomenon. If it were not known that the earth completes its rotation approximately every 24 hr, it would seem logical to attribute sunrise to the mere passage of time. A similar situation exists with the models proposed by Watson and Bower. More stringent tests of the models that go beyond the basic schedules of reinforcement are needed to address this concern.

Finally, it has been pointed out that the models at issue here require a degree of inference insofar as behavioral measures are used to index nonbehavioral events. Thus, the data generated by these models will be of limited utility to behavior analysis, but may nevertheless raise important issues and stimulate behavioral research.

The challenges faced by Bower's and Watson's models are common when one enters the cognitive realm. The processes that take place there are, for the most part, intangible. To the extent that cognitive models predict behavior in a manner consistent with operant principles, however, functionally parallel processes can be inferred. Such intersection will likely be the most productive in revealing the secrets of the black box.

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